An Overview of NASA's Activities in Micro-Nano Technologies

A Presentation for

3rd Roundtable on Micro-Nano Technologies for Space

John F. Stocky
Jet Propulsion Laboratory
California Institute of Technology
Thrust Area Manager for
Micro/Nano Sciencecraft
NASA's Cross Enterprise Technology Development Program

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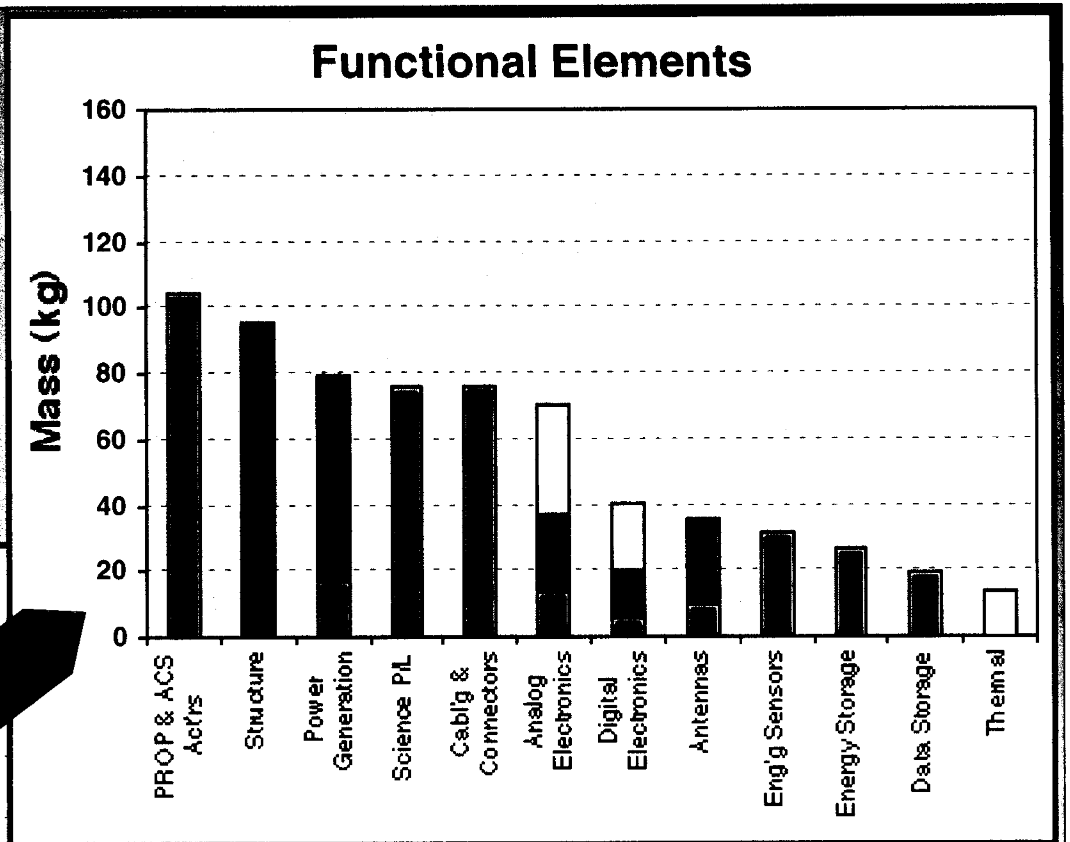
Discussion Topics

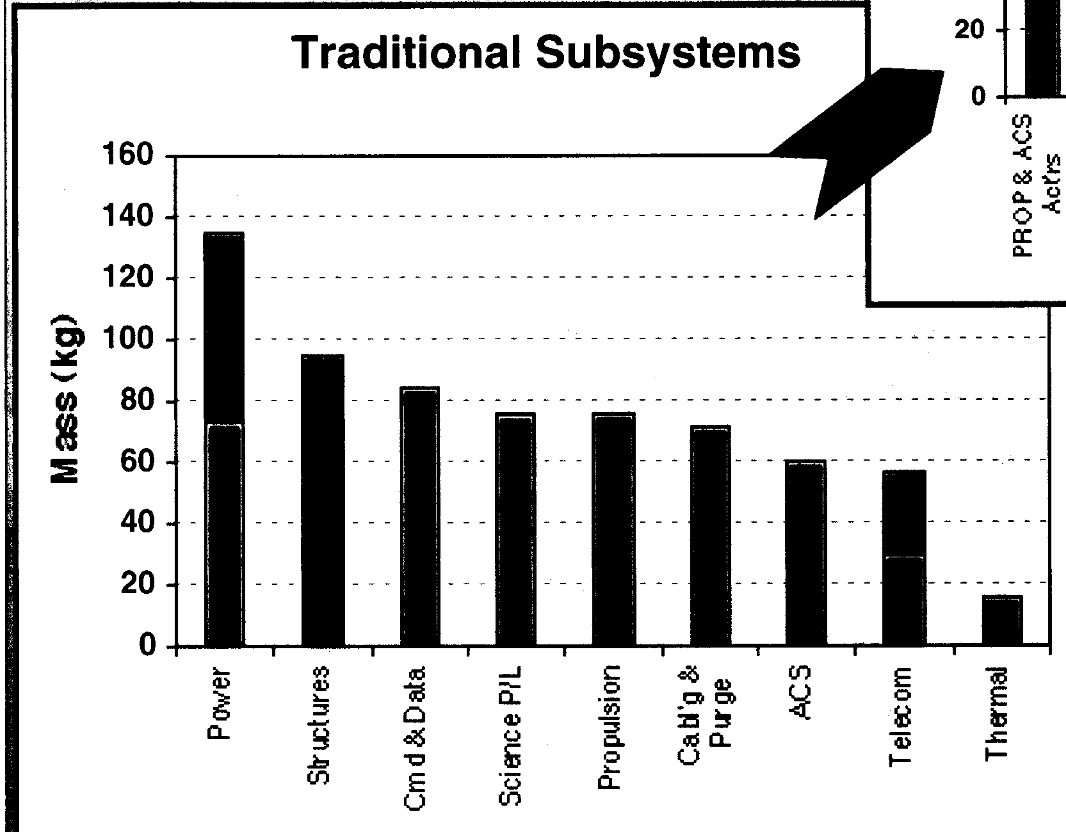
- Advanced Technology Needs and Goals
- Current NASA Activities
- Future Plans

Spacecraft Miniaturization Presents System Challenges

- **Past investments addressed a limited set of technical issues**
  - Much work largely in μ-electronics
    - Increased integration
    - Reduced power
    - Radiation hardness
  - Less attention paid to more "mechanical" elements of the spacecraft
- **Reducing the mass of spacecraft is a systems issue — a set of complex relationships**
  - Thermal
  - Power
  - Propulsion/dry mass

The Nature of Spacecraft Mass Reduction Depends on Point of View





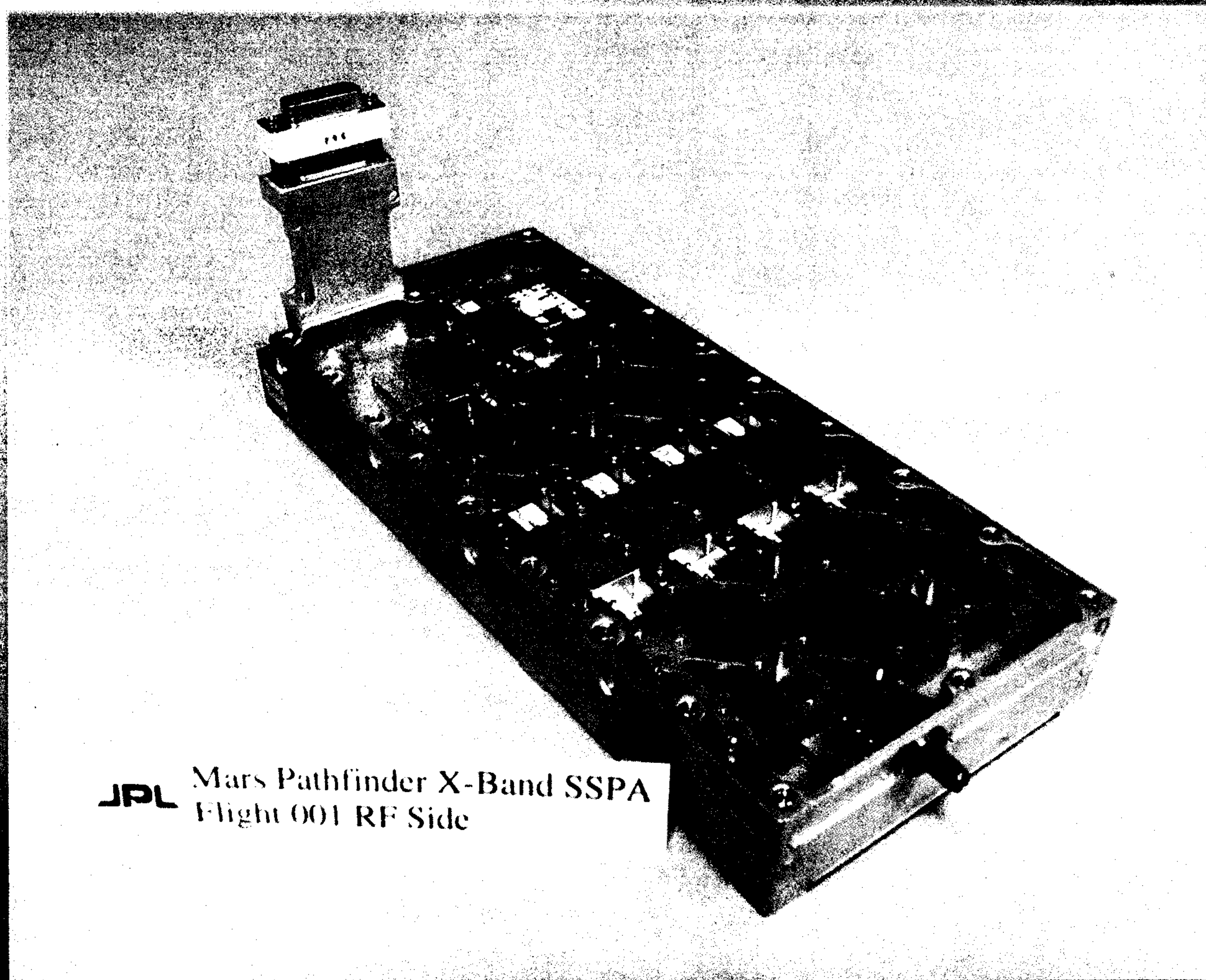
For Mars Global Surveyor

- Largest masses are actually dependent variables
  - Prop, ACS actuators, Structure, and Power
- Other masses are driven more by packaging, cabling, and thermal control masses than by that of electronics themselves

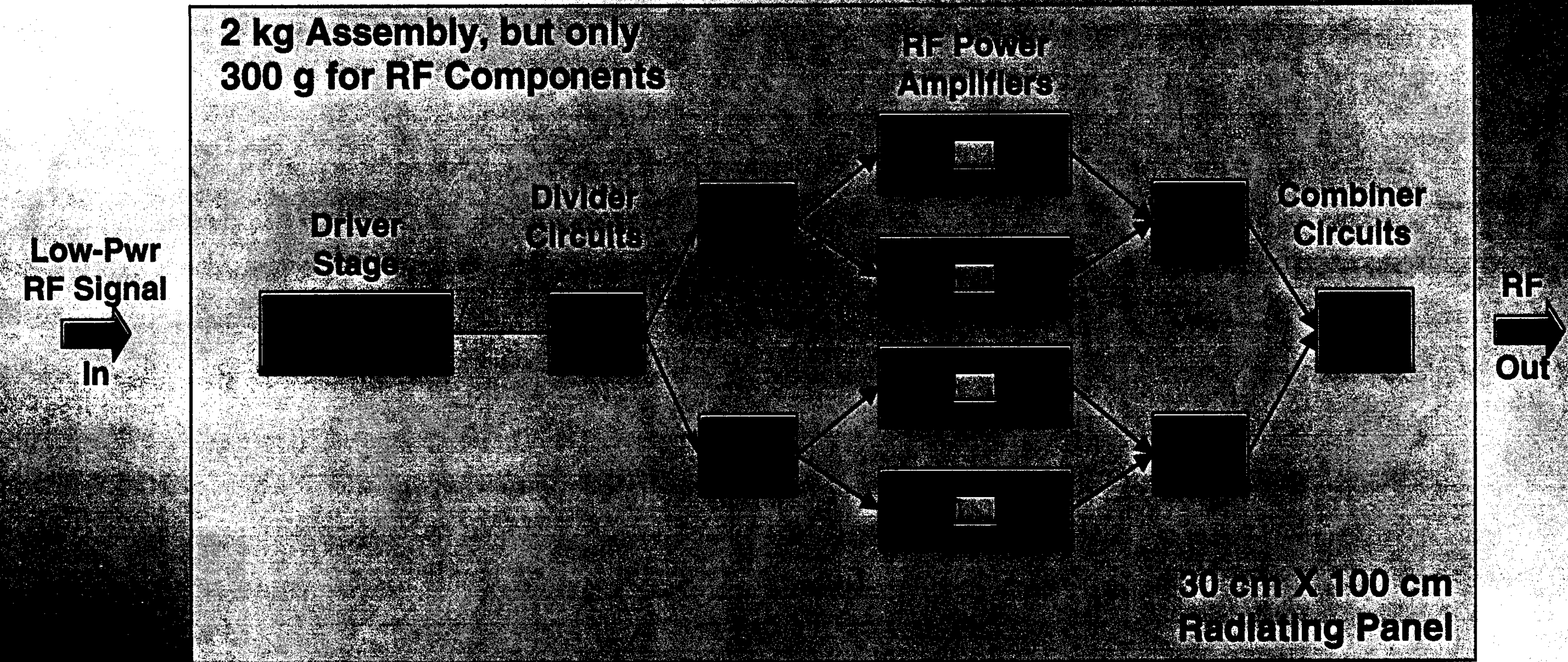
The DS1 RF Output Stage Illustrates the Systems Issues Associated with Spacecraft Mass Reduction

- Of the 60 W input only 12 W is radiated as RF signal
- The remainder must be radiated as heat
- To maintain an allowable temperature (100 C) at the RF chips, four elements must be used instead of a single one
  - This requires several passive circuits to split and recombine the RF signal
- The mass increased from 300 g for the elements alone to 2,000 g when packaged because of the multitude of elements and the amount of heat to be radiated.
  - The packaging design, driven by thermal considerations, required a large radiating surface (30 cm X 100 cm) and thicker sections than needed to satisfy structural requirements alone

DS1/Pathfinder X-Band Solid State [illegible] Illustrates Systems Nature of Technology Advances Needed To Reduce Spacecraft Mass



DS1 RF Output Stage Illustrates Interdependency of Comm, Thermal and Power Requirements



Smaller electronics is not always the path to lighter spacecraft. In this case, higher efficiency, improved thermal coupling, and reduced data rates are the remedies.

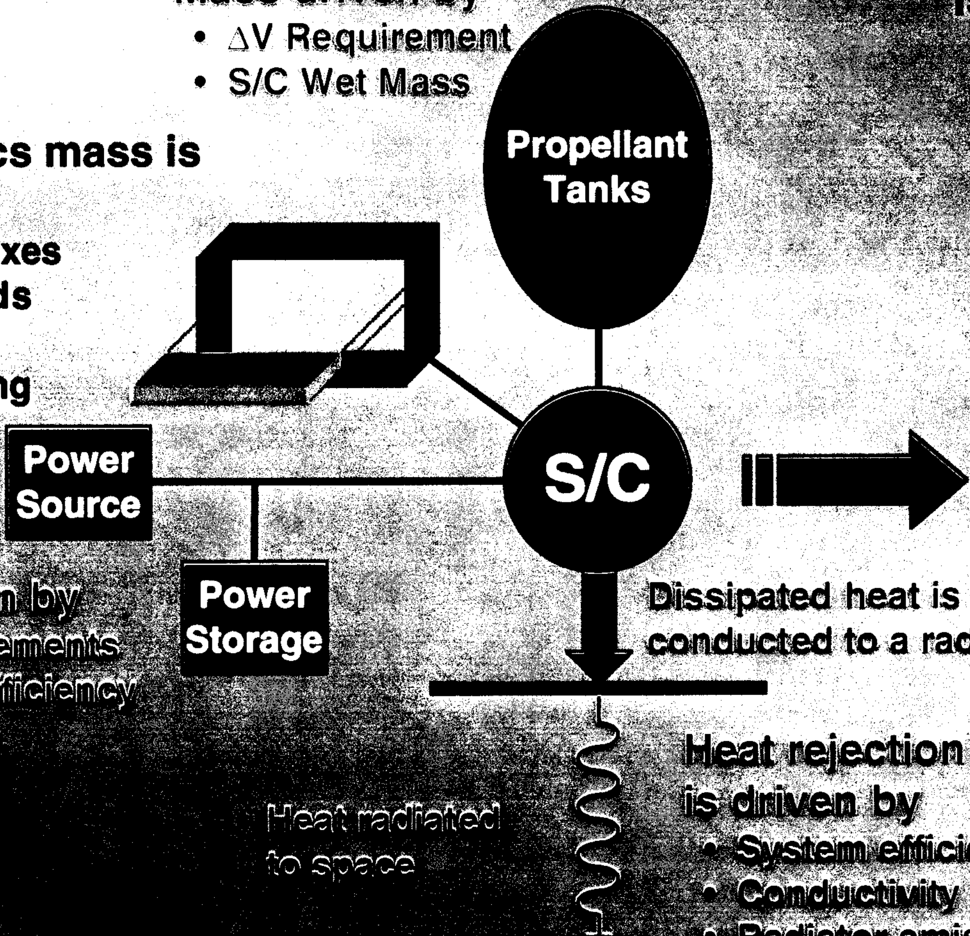
Technology Goal Setting Is [illegible] Matter of Mandating Smaller Components

- To reduce spacecraft mass an order of magnitude
  - Reduce RF power demands
    - Reduce data rate with data compression
    - Increase aperture, perhaps using an inflatable antenna
  - Reduce heat rejection mass via improved thermal properties
    - Diamond films
    - Carbon nanotubes
    - Higher emissivity surfaces
  - Improve electrical efficiency
    - Ultra-low power designs for digital electronics
    - Smaller analog components
    - More efficient analog circuits
  - Develop more mass efficient power generation and energy storage
    - More efficient solar arrays
    - Improved electrochemistry
    - Use containers as load-carrying structure
  - Reduce fraction of spacecraft used for propellant tank mass
    - Linerless, high-strength fiber wrapped tanks
    - Make part of load-carrying structure
  - Decrease the packaging mass associated with electronics
    - Load-carrying black boxes or multi-functional structures
    - [illegible] chip
    - Wireless data links

Reducing Spacecraft Mass Is Not Simply a Matter of Mandating Smaller Components

Mass driven by
- ΔV Requirement
- S/C Wet Mass

Electronics mass is driven by
- **Black boxes**
- **PC boards**
- **Cabling**
- **Packaging**



Mass driven by
- RF requirements
- System efficiency

Key to Reducing Mass Is Increasing:
- **Electrical efficiency**
- **Thermal conductivity**
- **Specific power**
- **Specific energy storage**
- **Propellant tank strength**
- **Electronics packaging**

Radiated RF Power
- Data Rate
- Distance
- Aperture

Dissipated heat is conducted to a radiator

Heat radiated to space

Heat rejection mass is driven by
- System efficiency
- Conductivity
- Radiator emissivity

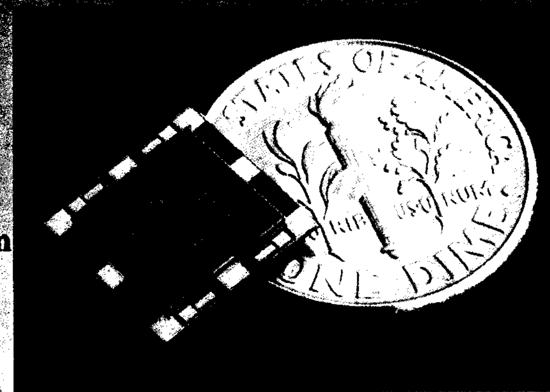
NASA's Current Activities

- NASA's overall goal is to provide the needed, unique technology advances in micro-device technologies that will allow an order of magnitude reduction in spacecraft size or a corresponding increase in spacecraft capability
  - Cross Enterprise Technology Development Program
    - Ultra-Low-Power, radiation tolerant digital electronics
    - Mixed-signal integrated electronics
    - μ-Gyro
    - On-chip data compression
    - Linerless, fiber-wrapped propellant tanks
  - System on a Chip
    - μ-Communications
    - μ-Passive components
    - μ-Power sources
    - μ-ACS Sensors
    - μ-Device packaging
  - X-2000 — A focused technology program
    - [illegible] Advanced technology μ-avionics for Europa Orbiter and Pluto Flyby
    - [illegible] Long-lived, radiation hard (100 M-Rad), scalable avionics system
    - [illegible] system for many future applications

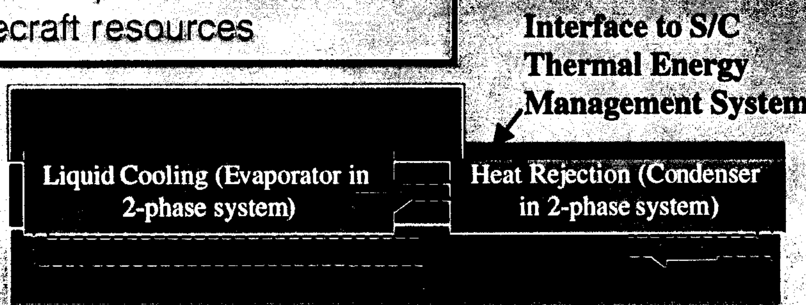
Current Activities by NASA Approach Mass Reduction from Many Different Directions

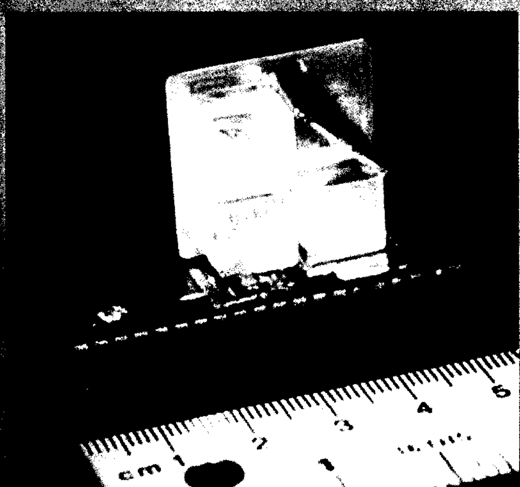
Common Goal: Establish the capability to reduce the mass of a spacecraft by a factor of ten, compared to the 1995 state of the art, by using the techniques of miniaturization to reduce both component size and the demands for spacecraft resources

Micro-Scale Gyroscope



On-Chip Liquid Cooling
μ-Channels, μ-Pumps, and Integrated μ-Cooling System





μ-Electronics and MEMS can reduce spacecraft mass by improving packaging, thermal performance, and reducing power demands

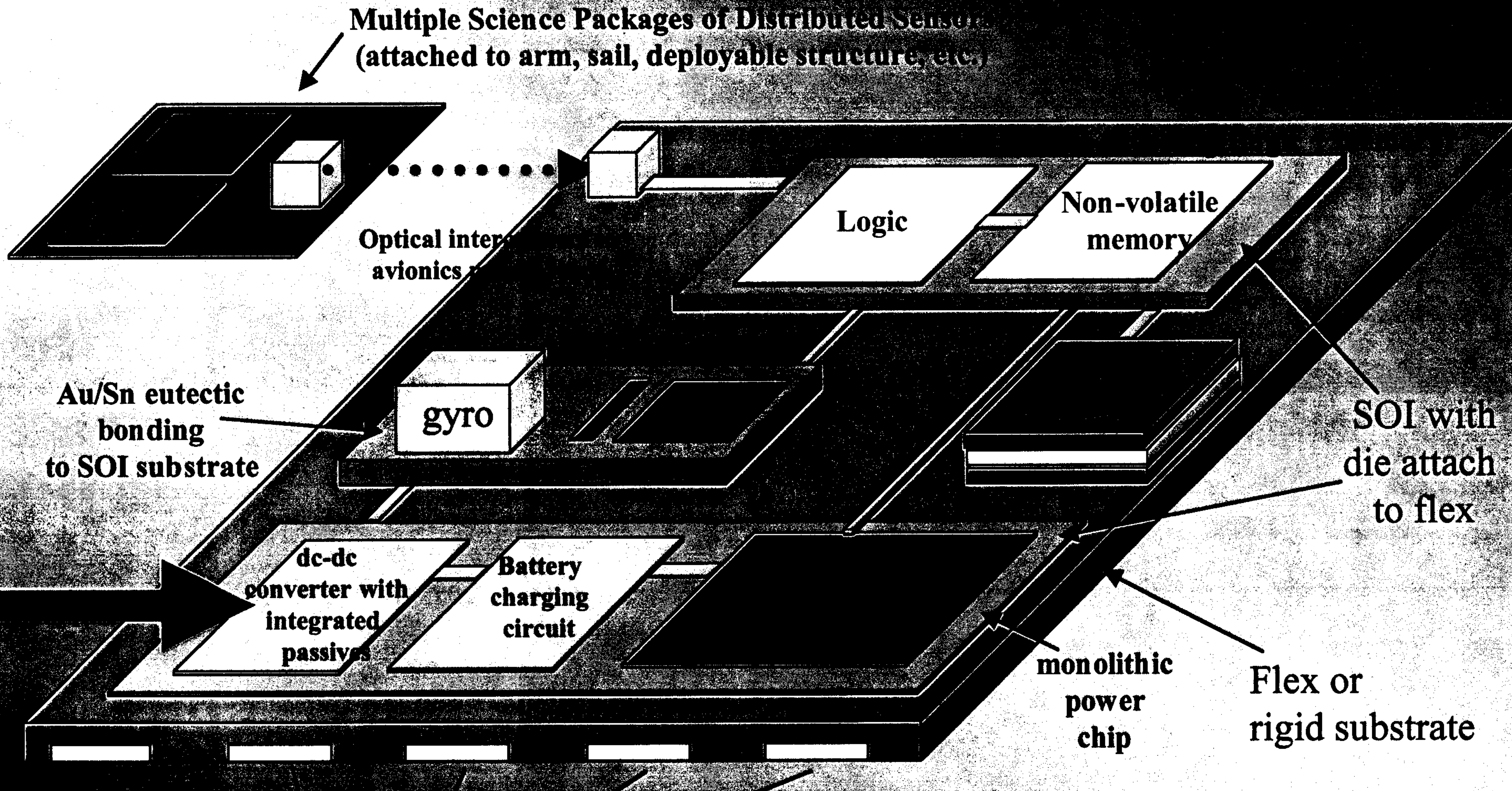
- **Reduce packaging and cabling mass by System on a Chip**
- **Reduced thermal mass by improved thermal conductivity between electronic heat sources and thermal radiators**
- **Reduced mass and power for data storage**
- **μ-Gyro and μ-Accelerometers reduce ACS sensor mass and power requirements**

Avionics Micro-System Enabled by SOAC Technology

- System on a Chip (SOAC) is a NASA technology initiative and is part of the CISM* program
- SOAC is focused on establishing the capability to place the entire complement of a spacecraft's avionics package on a single chip
- Significant mass savings result
  - Reduced mass for ACS sensors
  - Reduced packaging and cabling mass
  - Reduced power dissipation

* [illegible] Microelectronics

Avionics Microsystem enabled by SOAC technology



Products are highly adaptable and modular and can be configured to any mission type (sails, rovers, cluster missions) using advanced die attach, and wafer scale and 3-D packaging

NASA's Activities Are Part of a Larger National Effort

NASA's programs in micro-electronics and micro-~~devices~~ devices are but a part of the activities being conducted in this area in the U. S. NASA's work is intended to support the needs of NASA's missions, both robotic and crewed.

In addition the U. S. Department of Defense supports substantial advanced technology activities in these areas.

All these activities, whether supported by NASA or by some other agency, [redacted] are directed toward improving [illegible] making real the benefits of micro-[illegible]

NASA's Activities Are Part of a Larger National Effort

- Almost every agency in the U. S. government that has technical responsibilities has a program in micro-devices.
- DARPA Microsystems Technology Office has one of the most extensive
  - Photonics
  - Electronics
  - Micro-Electromechanical Systems (MEMS)
    - Merge information processing with sensing and actuation to realize new systems and strategies to bring co-located perception and control to the physical, biological, and chemical environment.
      - Demonstrate key devices, processes and prototype systems using MEMS technologies
      - Develop and insert MEMS products into commercial and defense systems
      - Lower the barriers to access and commercialization by catalyzing an infrastructure that can support shared, multi-user design, fabrication, and testing

NASA's Advanced Technology Initiatives

- In 5 to 10 years, the technology advances associated with μ-electronics and MEMS are expected to have reached the point of diminishing returns
- Three new advanced technology initiatives will take the agency into the twenty-first century
  - Information Technology
  - Bio-Technology
  - Nano-Technology
    - NASA is one of the US agencies participating in the national nano-technology initiative headed by NIH

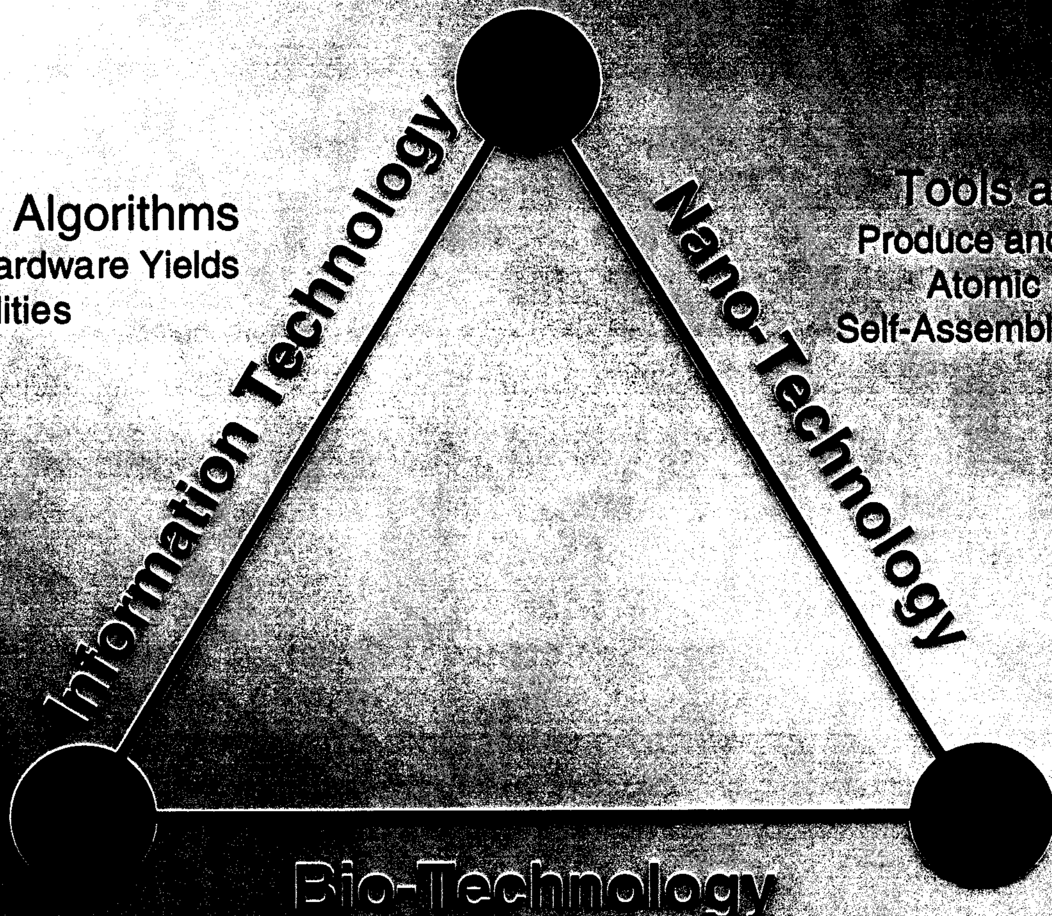
- Information Technology
  - Architectures and Algorithms
    - Enable new capabilities, e.g. active fault tolerance
    - Enabled by and enables new advanced hardware
- Bio-Technology
  - Detect presence of life in the universe, past or present
  - Maintain astronaut health on long-duration crewed missions
- Nano-Technology
  - $\leq$ 100 nm
  - Build from atomic scale
  - Self-Assembly

NASA's New Advanced Technology

NASA's technological future lies in the ... relationship of these three initiatives

Architectures and Algorithms

New Tools and New Hardware Yields
New Capabilities



Tools and Techniques

Produce and Use Nano-Materials
Atomic Scale Operations
Self-Assembly of Molecular Devices

... Health on Long-Term Missions

... of Present or Past Life in the Universe

Future Directions

Changes in NASA's advanced technology programs precede changes in developed hardware by five years or more. At this writing the diminution of advanced technology activities in micro-devices, activities grounded in techniques pioneered in the early days of the microelectronics revolution, can be seen.

Though practical micro-devices based on these techniques will continue to be developed for decades to come, the focus of the advanced technology community is already beginning to shift to nanotechnology. Nanotechnology offers the promise of capabilities only dimly seen today. The potential of in vivo health monitoring, critical for the health of astronauts on long-duration space missions, is only one of the many possible capabilities that can be foreseen.

Today work is being pursued to fabricate nano-materials like nanotubes, molecular circuits, and self-assembled systems using the tools of biology and chemistry. Analyses are being conducted to help determine directions and techniques uses quantum mechanical models to predict properties and benefits. Experimental work to identify the approaches that will bear productive fruit are being pursued in laboratories and universities throughout the world.

This investigative activity has borne enough fruit that the U. S. has begun a national [illegible] initiative, headed by the U. S. National Institute of Health, in which NASA [illegible] will form the base on which NASA's future ability to explore [illegible]

Future Directions

During the next five years:

- Advanced technology in μ-electronics and μ-devices to enable the development of spacecraft an order of magnitude less massive than those possible in 1995, while retaining the same functional capability
- Information technology advances will give those spacecraft capabilities far beyond that possible in 1995
- The first laboratory devices using nano-technology and nano-bio-technology emerge
  - *In vivo* monitoring of astronaut health
  - Advanced materials based on carbon nanotubes
    - High strength
    - High thermal and electrical conductivity
  - Nano-electronic devices
    - Semiconductor properties of carbon nanotubes
    - Molecular circuits

Nano-tube picture

Organic Circuit picture

Nano-bio Technology picture